A Comparison of At-A-Station Hydraulic Geometry for Step-Pool Channels

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1.0 Objective

This study compares the at-a-station hydraulic geometry for step-pool channels from several different locations to assess whether step-pool channels respond the same way to changes in discharge.

2.0 Background

The hydraulic geometry of a stream channel is a series of functional expressions that define the relationship between discharge and given hydraulic factors. While several expressions can be defined, the most commonly used ones are

$$w = aQ^b \qquad d = cQ^f \qquad v = kQ^m$$

where w = top width, d = hydraulic depth, v = mean velocity, Q = discharge, and a, b, c, f, k, and m are constants.

Since $Q = wdv$, then $b + f + m = 1$.

While past studies have shown that stream channels exhibit a very wide variation in hydraulic geometry exponents (e.g., Rhodes 1977), several workers have suggested that channels having similar structural or environmental characteristics should have similar hydraulic geometries (e.g., Park 1977, Rosgen 1994). This suggestion is examined here using step-pool channels.

Step-pool channels consist of an alternating series of relatively flat or low gradient sections separated by short, steep sections; and they have been observed in mountainous areas across the globe. While displaying wide variation in their morphologic features within individual sites, past reviews (e.g., Chin and Wohl 2005) have shown that step-pool channels exhibit many similarities in form relationships (e.g., step length vs. channel slope) between sites. Such similarities in form suggest they should also exhibit similar hydraulic geometries.

3.0 Methods

3.1 Data Sources and Models

Hydraulic geometries are compared using the b, f, and m exponents from power function models computed for each site. Hydraulic geometry data or models were obtained from published and unpublished sources. Discharge and cross-section measurements varied somewhat between sources, but I judged all of the methods used to be equivalent.

3.2 Analysis

Hydraulic geometry exponents were compared by plotting the b, f, and m triplets for each site on ternary diagrams. Two methods were used to adjust exponent triplets that did not sum to one: (1) proportional adjustment based on the relative size of each exponent at a site; and (2) Rhodes (1977) method of adjusting f and m. The differences in adjusted exponents between the two methods were generally very small (< 5% change) and did not greatly affect plotting positions; therefore only the exponents based on method 1 are discussed.

4.0 Results and Discussion

4.1 Exponent Variability

Wide variability is evident between the different sites despite their morphologic similarities (Figure 1 and Table 1).

Table 1. Variability of model exponents for step-pool hydraulic geometries.

	Exponent		
	Width	Depth	Velocity
Minimum	0.00	0.22	0.27
Maximum	0.38	0.69	0.68
Range	0.38	0.47	0.41
% of Sites Where Minimum	95.5	4.5	0
% of Sites Where Maximum	0	31.8	68.2

Variability between sites occurring in the same region is as high as that between all sites together (e.g., Colorado and Arkansas sites).

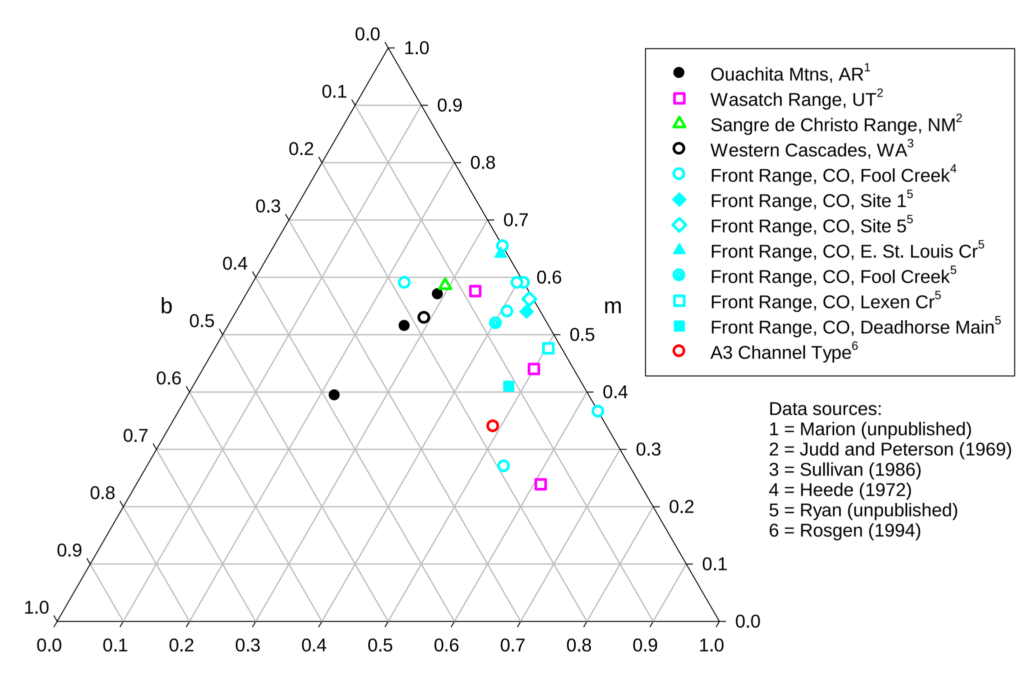

Figure 1. Hydraulic geometry exponents for step-pool sites.

Stratifying the sample by bed material size (D_{50}) does not reduce the variability (Figure 2).

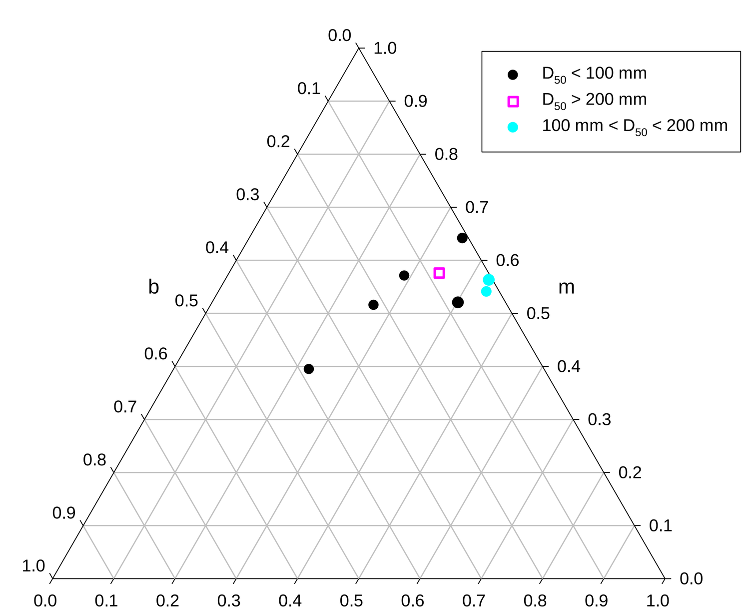

Figure 2. Hydraulic geometry exponents for step-pool sites reporting bed material D_{50} size.

Some similarities are evident. The depth and velocity exponents are generally much greater than the width exponent. The velocity exponent is usually greater than depth, indicating that velocity changes faster than depth as flow increases. Width changes very slowly with discharge change.

4.0 (continued)

4.2 Response Patterns

Rhodes (1977) used the rate and direction of change in width-depth ratio, competence, Froude number, velocity-cross-sectional area ratio, and slope-roughness ratio to define 10 hydraulic geometry classes. He reasoned that sites within a given class would respond in the same way to discharge changes, but may vary in their response rates.

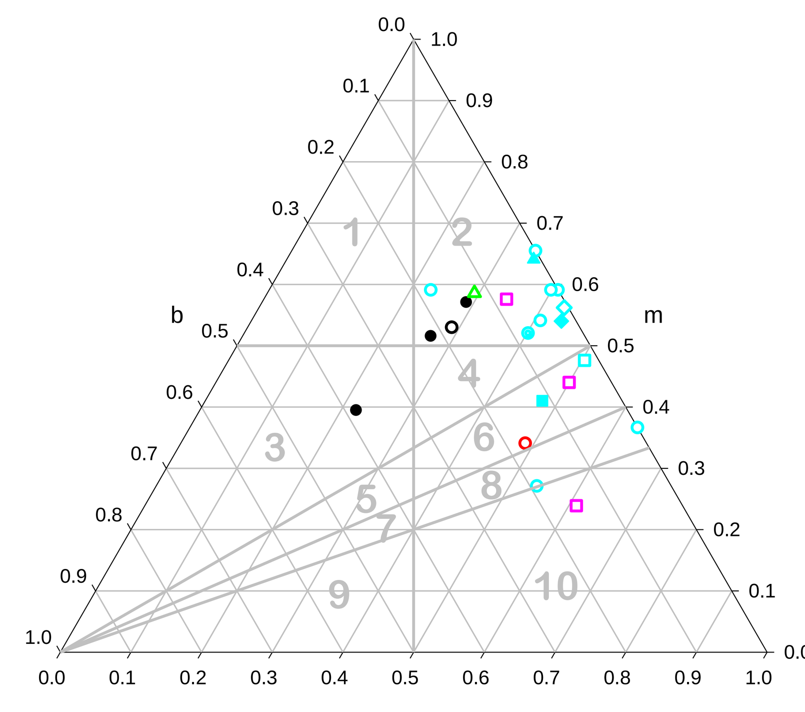

Figure 3. Hydraulic geometry exponents for step-pool sites showing Rhodes (1977) classes (gray lines and numbers).

Over 60% of the step-pool sites fall within one class (class 2), and over 80% fall with one of two classes (classes 2 and 6) (Figure 3).

The primary difference between class 2 and 6 is that class 6 sites would exhibit a faster increase in cross-sectional area than velocity with increased discharge; whereas class 2 sites to exhibit the opposite relationship (Table 2).

Table 2. Expected change in hydraulic parameter with discharge increase (Rhodes 1977).

Channel Class	Width-Depth Ratio	Competence	Froude Number	Velocity-Area ratio	Slope-Roughness ratio
2	Decrease	Increase	Increase	Increase	Increase
6	Decrease		Increase	Decrease	Increase
8	Decrease		Increase	Decrease	Decrease
10	Decrease		Decrease	Decrease	Decrease

4.3 Explanation of Differences

The following reasons have been suggested previously to explained differences in hydraulic geometries; however I deem them *unlikely* given the data, site similarities, and methods that I used (possible exceptions are in parentheses):

- Differences in relative flow magnitudes (Heede's sites)
- Using gauging sites or multiple sites (Rosgen A3 sites)
- Using different methods of model derivation
- Differences in bank composition, bed material size, suspended sediment load, riparian vegetation, channel stability, or climate and flow regime

4.3 (continued)

Two explanations for the observed differences do seem *plausible*.

Channel pattern – One site is split into two channels at lower flows; it plots within Rhodes' (1977) class 3, the class containing braided channels. To my knowledge, no other site has multiple channels.

Channel Size vs. Bed Material Size – Ryan (personal communication) has suggested that differences in channel size relative to bed material size might explain how channels with smaller widths and bed material caliber might exhibit the same morphologic pattern as channels with larger widths and bed material, yet exhibit different rates of hydraulic change with discharge changes. The sites with smaller basin areas and D_{50} sizes (AR, WA, and Ryan's Fool Creek and Deadhorse Main) do have larger b values, but more data will be needed to examine this hypothesis.

5.0 Conclusions

- Despite similarities in morphologic form, step-pool channels do *not* exhibit a high degree of similarity in the *rates* at which width, depth, and velocity change in response to discharge.
- Step-pool channels *do* exhibit a moderate degree of similarity in the *way* in which they respond – that is, the direction of hydraulic changes are similar between most sites, even though individual rates may vary noticeably.
- Thus, knowledge of gross morphologic form can provide insight into the general manner in which a channel will respond to discharge changes, but it does not determine the individual rates at which width, depth, and velocity change.

6.0 Acknowledgements

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